PERFORMANCE OF THE μA703 IN 100-MHz and 200-MHz AMPLIFIERS AND 100-MHz HARMONIC MIXERS

by David Bingham

ABSTRACT

The μA703 has a useful frequency range extending to slightly above 200 MHz. As such, it may be used either as an amplifier (saturating or non-saturating) or as a harmonic mixer. This Application Bulletin describes the performance of the μA703 in 100-MHz and 200-MHz amplifiers and as a harmonic converter or mixer from 100 MHz to 10.7MHz.

Description of μA703

The μA703 is a linear integrated circuit using two small high-frequency transistors as an emitter-coupled pair for RF amplification. These transistors are similar in some respects to the Fairchild 2N9918 transistors, which are also useful as amplifiers up to several hundred megahertz. Although the emitter-coupled pair has a higher noise figure than a single transistor, the μA703 provides a higher stability-limited power gain and a higher maximum available power gain (MAG). One advantage in integrating an emitter-coupled pair rather than using discrete transistors is a reduced reverse transfer capacitance. This is because each transistor is separated from other components by an isolation area connected to ground. Any bonding pads to which the external leads are connected can therefore lie over an isolation area instead of over the collector region, thus reducing the collector to emitter or collector to base reverse transfer capacitances. Refer to Figure 1.

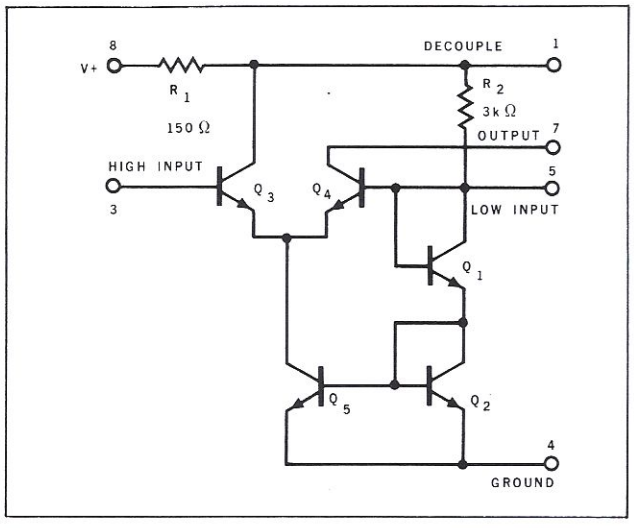

Fig. 1. μA703 schematic.

PERFORMANCE MEASUREMENTS

100-MHz Power-Gain

Figure 2 shows the schematic of the jig designed to measure the power gain of the μA703 at 100 MHz. As with all circuits using the μA703 at frequencies above 30 MHz,

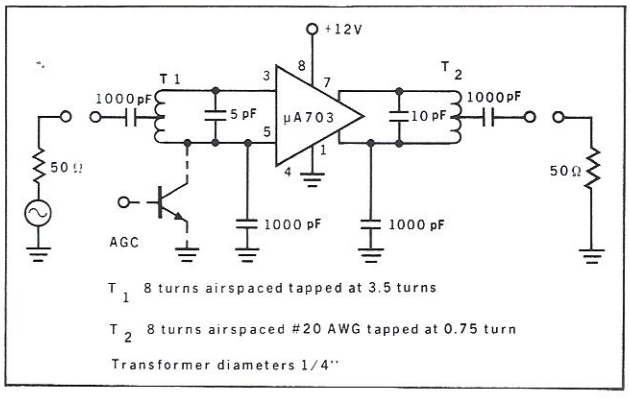

Fig. 2. 100-MHz test jig.

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the low-input terminal (pin 5, Figure 2) should be decoupled to ground. This is necessary for two reasons. First, the two diodes, Q_1 and Q_2 (or saturated transistors) between pins 5 and 4 do not perform as a perfect short-circuit and so do not completely decouple the base of the grounded-base transistor (Q_4) of the emitter-coupled pair. Second, the high-frequency current gain is falling off at 6 db per octave at frequencies above 30 MHz, resulting in more base current at high frequencies and, consequently, more RF current in the two decoupling diodes or external decoupling capacitors.

Without the bypass capacitance at pin 5, both the power gain and the gain figure at 100 MHz for μA703 are decreased by about 8 db under the parameters listed below

TABLE I.
TYPICAL μA703 PERFORMANCE.
(12-volt power supply, f = 100-MHz)

PARAMETER	MEASUREMENT
Power Gain	21.5 db
Noise figure	6 db
Bandwidth (-3 db)	5 MHz
Gain figure	$\left\|\frac{Y_{21}}{Y_{12}}\right\|^2 = 62$ db
Gain maximum stable	$\left\|\frac{Y_{21}}{Y_{12}}\right\| = 31$ db

The y parameters at 100-MHz are:

$$y_{11} = 1.2 + j\ 3\text{mmhos}$$

$$y_{22} = 0.2 + j\ 1.5\text{mmhos}$$

$$\left|y_{21}\right| = 19\ \text{mmhos}$$

$$\left|y_{12}\right| = 0.015\ \text{mmhos}$$

The μA703 may be used as current mode limiter if the total output admittance including g_{22} is greater than about 0.3 mmho. The power gain using the μA703 as a current mode limiter will be 21 decibels.

Reverse AGC may be obtained by bleeding current from pin 5, thereby reducing the value of the current in the emitter-coupled pair. This can be conveniently accomplished by the use of an external transistor shown in dotted out-line in Fig. 2.

200-MHz Power Gain

The jig (Figure 3) for the measurement of power gain and noise figure at 200-MHz is essentially the same as the one used at 100-MHz with, of course, changes in the values of the tuning components.

TABLE II.
TYPICAL 200-MHz μA703 PERFORMANCE.
(12-volt supply, f = 200-MHz)

PARAMETER	MEASUREMENT
Power gain	14 db
Noise figure	7.5 db
Bandwidth (-3 db)	10 MHz
Gain figure	41.5 db (Ratio of forward to reverse gain.)
Gain maximum stable	20.5 db

The y parameters for the μA703 at 200-MHz are:

$$y_{11} = 2 + j\ 6.3\text{mmhos}$$

$$y_{22} = 0.7 + j\ 6.3\text{mmhos}$$

$$y_{21} = 12\ \text{mmhos}$$

$$y_{12} = 0.12\ \text{mmhos}$$

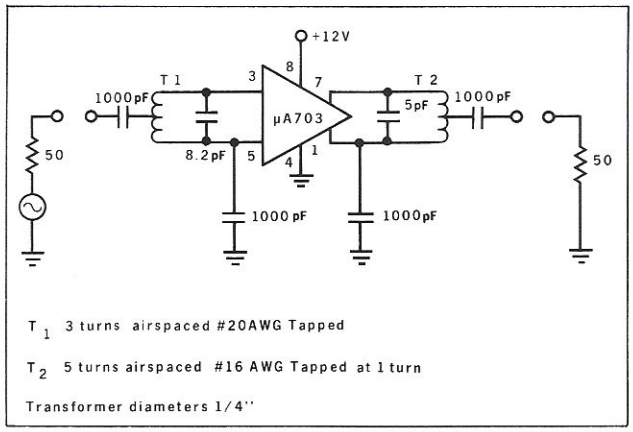

Fig. 3. 200-MHz test jig.

100-MHz Harmonic Mixer

The emitter-coupled pair is ideally suited for harmonic mixer applications but is not suitable for conventional mixing (i.e., where the IF frequency is equal to the sum or difference of the incoming signal and local oscillator signal). The reason for this is due to the unique properties of the g_m. If the emitter-coupled pair has the dc current in each transistor defined by a current source, as is the case of the μA703, then the g_m can be represented by the following expressions.

$$g_m = \frac{\frac{Ai}{k} e^{-AVin}}{\left(e^{-AVin} + 1\right)^2} \qquad (1)$$

where $A = \frac{q}{kT} = 40$ (approx), and i_k = current defined by current source in milliamperes.

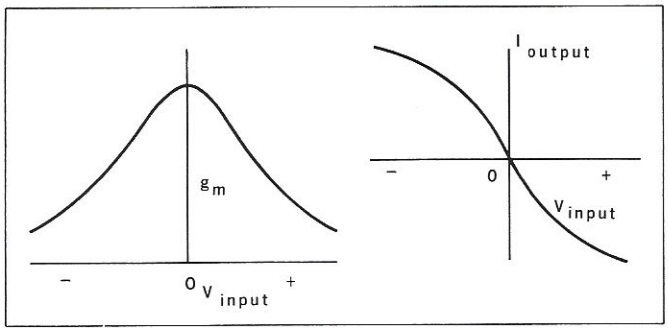

Fig. 4. Output current and g_m plotted against input voltage.

For mixer action to occur, the injected oscillator signal has to convert the g_m into a time-varying function. Therefore, if the injected oscillator voltage, $V_0\cos\omega_0 t$, is substituted in Equation 1 for V_{in}, the g_m becomes

$$gm = \frac{-Ai_k e^{-AV_0\cos\omega_0 t}}{(e^{-Ai\cos\omega_0 t} + 1)^2} \quad (2)$$

$$\text{or} \quad g_m = \frac{-Ai_k e^{-AV_0\cos\omega_0 t}}{(e^{-AV_0\cos\omega_0 t} + 2e^{-AV_0\cos\omega_0 t} + 1)} \quad (3)$$

Expanding the exponential terms into power series,

$$g_m = \frac{-Ai_k\left(1 - AV_0\cos\omega_0 t + \frac{A^2V_0^2\cos^2\omega_0 t}{2!}\right)}{\left(4 - 4AV_0\cos\omega_0 t + 3A^2V_0^2\cos^2\omega_0 t - \frac{5A^3V_0^3\omega_0 t}{3} + \text{---}\right)}$$

$$= i_k(B_0 + B_1V_0^2\cos^2\omega_0 t + B_2V_0^4\cos^4\omega_0 t + \text{--------}) \quad (4)$$

Equation 4 can be expressed by

$$g_m = a_0 + a_2\cos + \omega_0 t + a_4\cos 4\omega_0 t + \text{----------} \quad (5)$$

The resultant g_m has a time-varying component at twice the oscillator signal frequency but no component at the oscillator frequency. Empirically, it has been verified that this second harmonic term increases as the square of the applied oscillator signal until about 50 mVs rms, then increases only slightly to about 100 mVs rms, after which it decreases.

The output current from the harmonic mixer is the product of the input signal and the time-varying g_m (assuming that the input signal is very small).

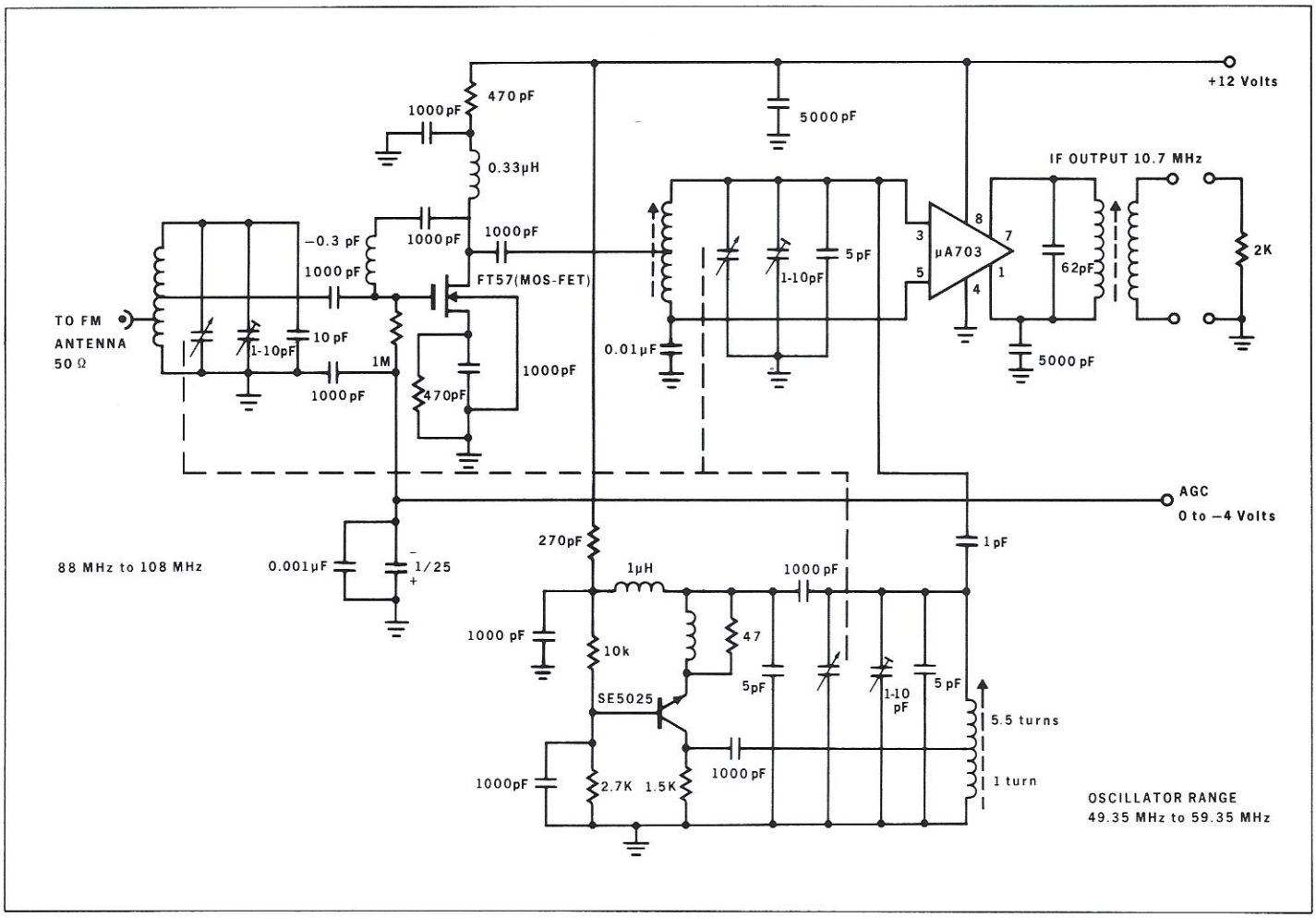

Fig. 5. FM tuner with µA703 harmonic mixer.

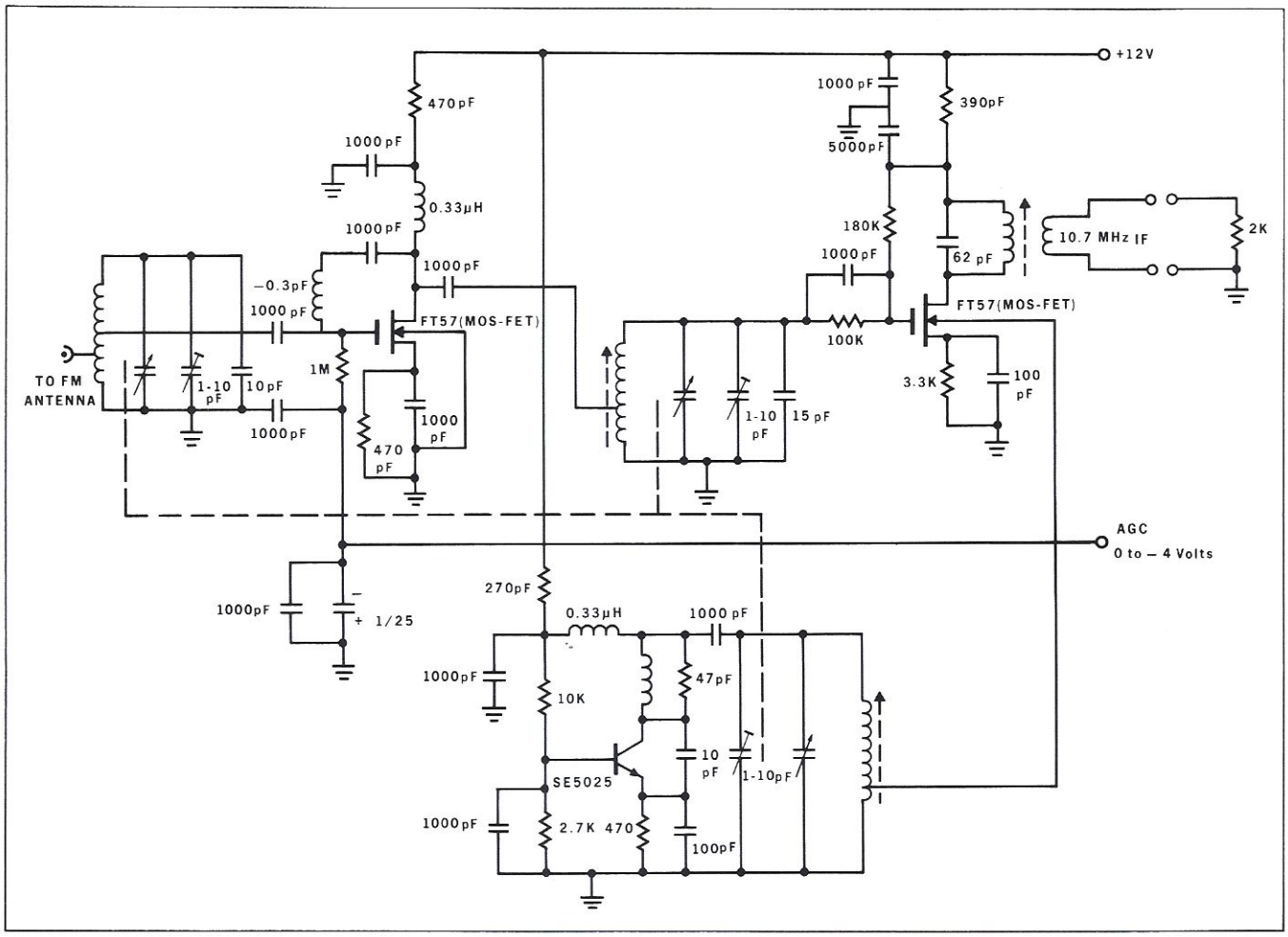

Fig. 6. FM tuner using MOS-FET transistors (FT 57).

Therefore, the output current,

$$I_{out} = g_m V_{in} \text{ (desired)}$$

$$= \acute{a}_0 \cos\omega_1 t + \acute{a}_2 \cos 2\omega_0 t \cos\omega_1 t + \acute{a}_4 \cos 4\omega_0 t \cos\omega_1 t + \text{---}. \quad (6)$$

Where $V_{in} = a \cos\omega_1 t$,

$$I_{in} = \acute{a}_0 \cos\omega_1 t + \frac{\acute{a}_2}{2} \cos(2\omega_0 + \omega_1)t + \cos(2\omega_0 - \omega_1)t + \frac{\acute{a}_4}{4} \left\{ \cos(4\omega_0 + \omega_1 t + \cos(4\omega_0 - \omega_1)t \right\} + \text{-----} \quad (7)$$

Equation 6 has some interesting implications which, at first sight, would appear to be applicable to FM tuners; namely, that the spurious responses should be zero, with the exception of the image response and that, since there are no third or odd harmonic terms, cross-modulation products should not exist. However, two assumptions were made in the analysis:

1) The transistors were assumed ideal.

2) The input signal would always remain small with respect to the injected oscillator signal (which) is not greater than 100 mV).

If the desired input signal is very large, the emitter-coupled pair will act as a switch and the mathematical complexity becomes extremely involved. Therefore, an FM tuner was used to evaluate the performance of the μA703 and to compare it for the consumer market with a MOS-FET in the mixer position.

Figures 5 and 6 show the FM tuner using both the μA703 and the FT57 MOS-FET. In both cases, the same RF amplifier and interstage transformer were used. The oscillator was modified to the minimum extent. The input admittance of the μA703 with about 100 mVs of oscillator signal injected is approximately 0.1 mmho; thereby allowing the μA703 to be coupled directly across the RF interstage transformer. For convenience, the oscillator voltage is injected into the "high" input of the μA703 through a 1-pf capacitance.

The gross overload of the tuner with the FT57 mixer is defined when the oscillator frequency is pulled by more than 10 KHz by the input signal to the tuner. The overload phenomenon with the μA703 mixer is due to the very rapid falloff of the conversion of g_m when the RF signal approaches and exceeds the oscillator signal in value. This action prevents the normal AGC from acting on the RF stage, because the falloff of mixer gain is at least as rapid as the increase in signal to the input of the tuner.

TABLE III.
COMPARATIVE PERFORMANCE DATA.
(With FM IF Amplifier and Conventional AGC Circuit)

PARAMETERS	TUNER WITH FT57 MIXER	TUNER WITH μA703 MIXER
Power Gain	20 db	31 db
Spurious rejection (IHF)	> 90 db	~70 db
Oscillator injection	600 mV	90 mV
Gross overload*	>200 mVs	~15 mVs

*Defined as maximum input signal to tuner prior to a limiting phenomenon.

The voltage gain from the antenna to the input of the μA703 mixer is between 25 and 30 db. It can be seen, therefore, that input signals in excess of 3 mVs will have an amplitude at the input of the μA703 similar to that of the oscillator.

The estimated power gain of the μA703 as a harmonic mixer in the FM tuner is about 14 db. No attempt was made to optimize the power gain by changing the output circuit matching.

As an experiment, the μA703 was operated as a conventional mixer to determine how closely theory agreed with practice. With an oscillator injection voltage of 100 mV to 200 mV at 110.7 MHz (IF frequency 10.7 MHz) and the desired signal at 100 MHz, the minimum insertion loss of the mixer was found to be about 15 db.

CONCLUSION

The μA703 has very useful power gain to frequencies in excess of 200 MHz and very low noise figures for an emitter-coupled pair configuration. In general, the μA703 is stable in any conventional small-signal amplifier at any frequency with conjugate input matching, and output matching either conjugate or less than 30,000 ohms, whichever is lower. The noise figure starts to increase at frequencies in excess of 50 MHz from about 4 db and is typically only 7.5 db at 200 MHz. Due to the inherent characteristics of an emitter-coupled pair of transistors, conventional sum and difference mixers are not possible. However, the μA703 is ideally suited for harmonic mixer applications to about 200 MHz, with good conversion gain and low noise.

ACKNOWLEDGMENT

The author gratefully acknowledges the analysis of the harmonic mixer by Hermann Ebenhoech.

APPENDIX

Equation 3 is rewritten here:

$$g_m = -Ai_k \left[\frac{e^{-AV_0\cos\omega_0 t}}{e^{-2AV_0\cos\omega_0 t} + 2e^{-AV_0\cos\omega_0 t} + 1} \right]$$

Dividing numerator and denominator by $e^{-AV_0\cos\omega_0 t}$ yields:

$$g_m = \left[\frac{Ai_k}{2 + e^{-AV_0\cos\omega_0 t} + e^{+AV_0\cos\omega_0 t}} \right]$$

since $e^{-AV_0\cos\omega_0 t} + e^{+AV_0\cos\omega_0 t} = 2\cosh(AV_0\cos\omega_0 t)$,

the result can be expressed as:

$$g_m = \frac{-Ai_k}{2} \left[\frac{1}{1 + \cosh(AV_0\cos\omega_0 t)} \right] \qquad (3a)$$

The cosh function is sketched in Figure 6. Let $\cos\omega_0 t$ go from +1 to -1 and back. It is not difficult to see that at $\cos\omega_0 t$ equal to -1, the cosh function has the same value as for $\cos\omega_0 t$ equal to +1. Therefore, $g_m(t)$ will have the same value in both cases. This means that g_m will twice attain the value corresponding to $\omega_0 t$ equal to zero, while $\omega_0 t$ varies from zero to 2π. Therefore, the g_m is periodic in $2\omega_0 t$.

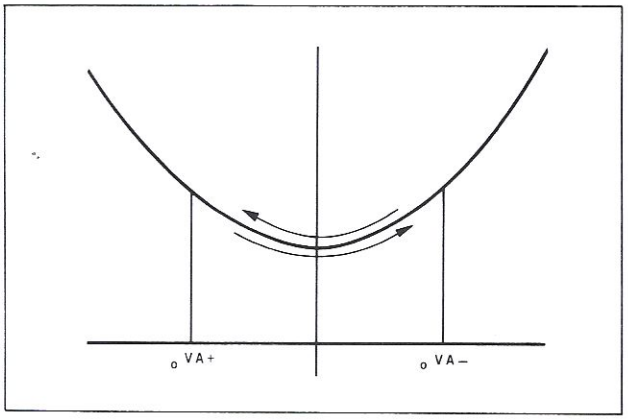

Fig. 7. Cosh function.

Let us call $2\omega_0 t = \omega_1 t$. Then the Fourier expansion of g_m will contain all harmonic frequencies of ω_1, or (in terms of ω_0), $2\omega_0 t$, $4\omega_0 t$, $6\omega_0 t$, ...

Therefore, no odd-order harmonics of ω_0 will appear in the output.

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